Institute of Transportation Studies
University of California, Davis

GIS-Based Studies of Hydrogen Infrastructure Systems and Transition Strategies

Michael Nicholas,
Zhenhong Lin, Jason Ni,
Nathan Parker, Jonathan Weinert,
Christopher Yang, Joan Ogden

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Background: H2 Pathways Program at UC Davis

Transportation and the Hydrogen Economy: Pathways and Strategies

- Multi-year interdisciplinary research program began 2003
- Strategies and Pathways for transportation sector Hydrogen
- Research, education, public process
- 17 research projects ongoing
- 10 senior researchers, 15 graduate student researchers
- 20 sponsors including OEMs, energy firms, government, environmental community

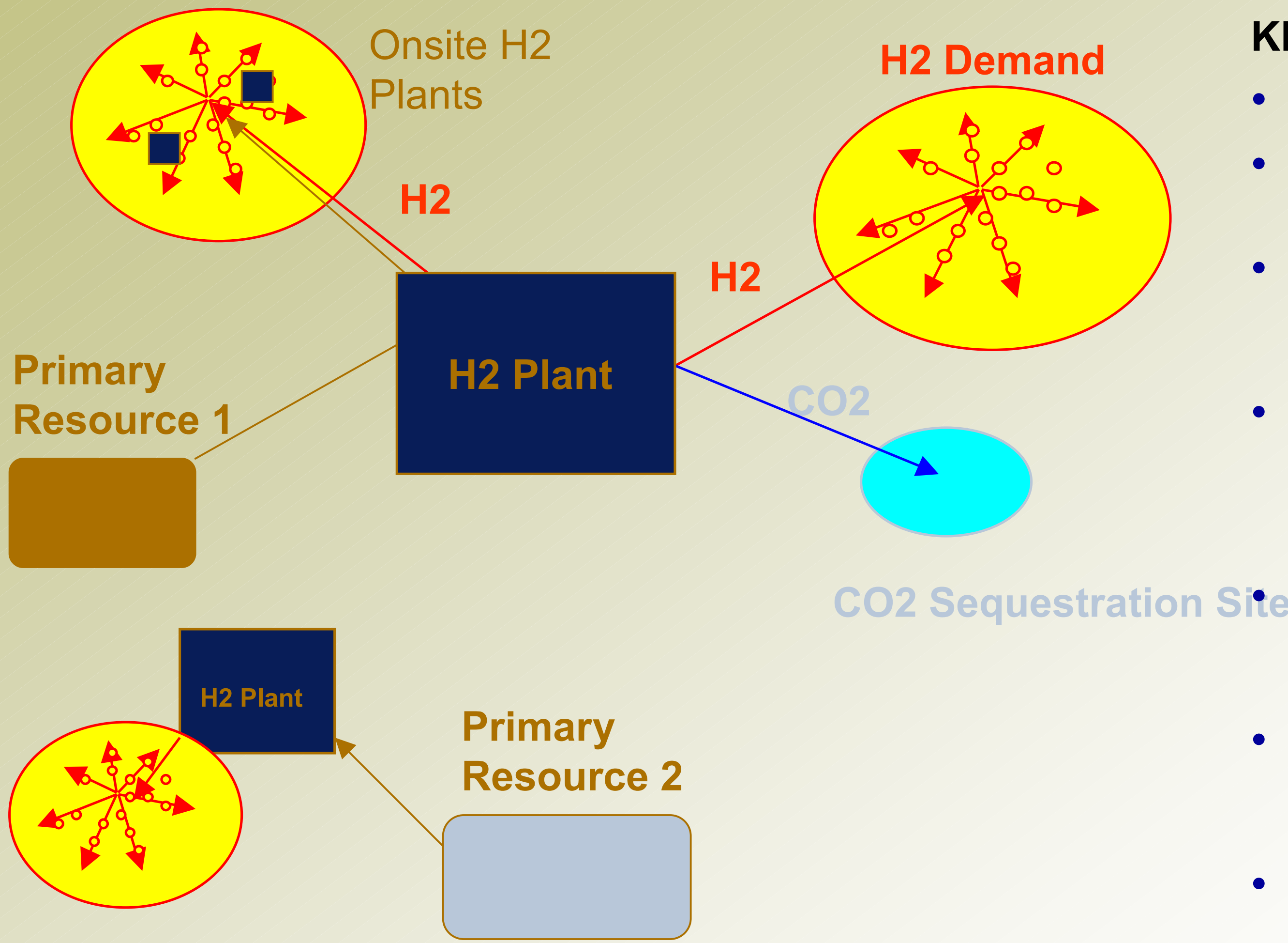
Design and Analysis of Hydrogen Infrastructure Systems and Transition Strategies

Need for systems analysis of H2 transition paths was highlighted in the recent NAS report on the Hydrogen Economy.
(Compare H_2 , other options.)

Understanding alternative H_2 transition strategies is seen as key analysis goal in the USDOE HFCIT Program Plan

Modeling regional H2 supply over time

What is the best (=low cost, low emission) system for producing and delivering H_2 to serve a growing demand?



KEY QUESTIONS:

- **Demand/markets?**
- **H2 Refueling stations? How many? Where?**
- **H_2 Plants: Size, Location? Onsite v. central production.**
- **Distribution: LH2 or GH2 truck, pipeline? Local, regional, or long distance?**
- **Use existing energy infrastructure/rights of way?**
- **Primary source? Associated externalities?**
- **Optimum paths over time?**

H2 Infrastructure Models: Current Status

- Many techno-economic studies of parts of system (H2 production, H2 delivery, refueling stations).
- Existing spreadsheet H2 system models (NAS, SFA, NREL, others) estimate cost, based on steady state demand, limited palette of H2 production, delivery system designs.
- DOE H2A EXCEL-based spreadsheet models of hydrogen system components, delivery scenarios available Fall ’04.
- Energy/economic, Integrated Assessment, Environmental models include “modules” on H2 (EIA/NEMS, PNNL, IIASA, EPA, GREET others)
- H2 Transition modeling underway at ORNL, Imperial College, Argonne National Laboratory, NREL, U. Michigan, UC Davis

H2 Infrastructure Models: What's Missing?

- Models connecting supply and demand; (Models of future markets/demand)
- **Geography; Regional Case studies**
- Dynamics; transition studies
- Include societal impact/policies
- Interaction with the rest of the energy system

H2 Pathways H2 Infrastructure System Models: Technical Approach

Develop increasingly sophisticated analytic and simulation tools to understand design, performance, economics, environmental characteristics, dynamics of entire system.

- Extend Engineering/Economic Spreadsheet Models to connect supply/demand, include market, geographic, technical factors and time dependence in a transparent way.
- Use planning tools such as GIS and mathematical programming/operations research to understand infrastructure evolution in particular regions. Case studies of regional H2 infrastructure development

Goals:

Model H2 demand and infrastructure development spatially and over time, based on a range of credible demand scenarios.

Develop understanding of how H2 transitions might occur under different geographic and market assumptions.

Ongoing Projects Using GIS as a Tool

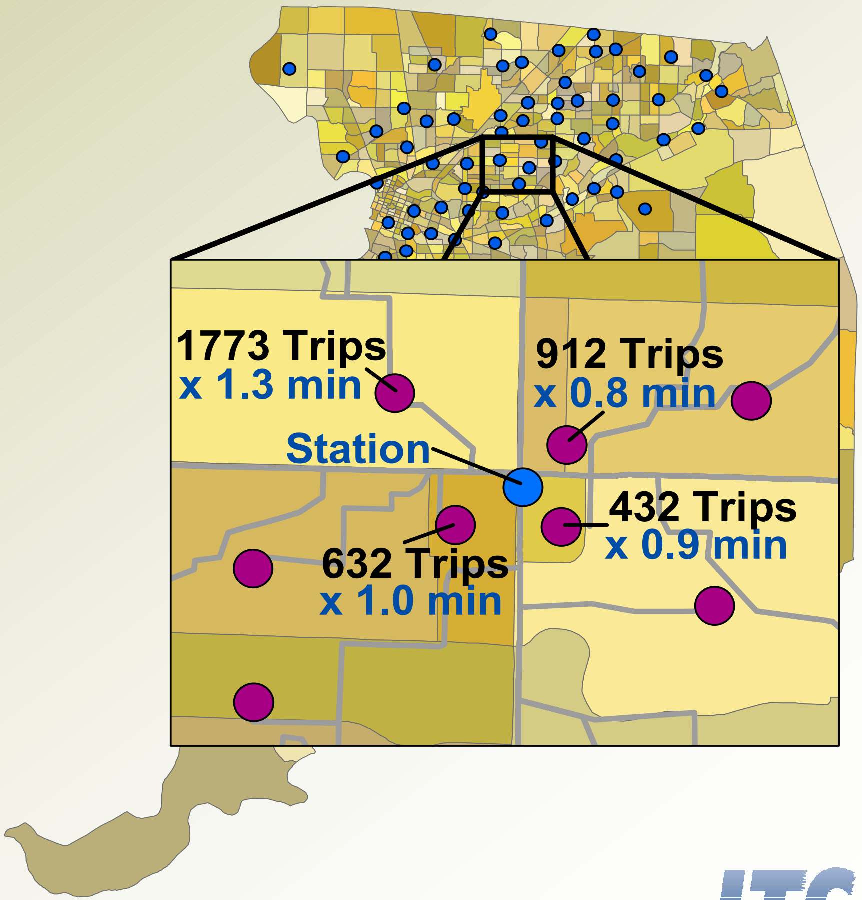
- GIS Analysis of Refueling Station Siting and H2 Infrastructure Deployment Strategies
- Development of GIS-Based Methods for Modeling Regional H2 Infrastructure Development

Evaluate Station Choices

- Compute the time required to go from the origin or destination Traffic Analysis Zone (TAZ) to the nearest hydrogen station

$$AvgTime = \sum_i (Trips * Minutes) \Big/ \sum_i Trips$$

Origin TAZ	Station	Trips	Minutes	Trips x Minutes
1	12	1773	1.3	2304.9
2	12	912	0.8	729.6
3	12	632	1.0	632.0
4	12	423	0.9	380.7
5	43	815	5.6	4546.9
↓ 700	↓ 20	↓ 420	↓ 3.7	↓ 1554
Sum		474480		1462454
Trip Min Sum / Trip Sum				Avg Time 3.082



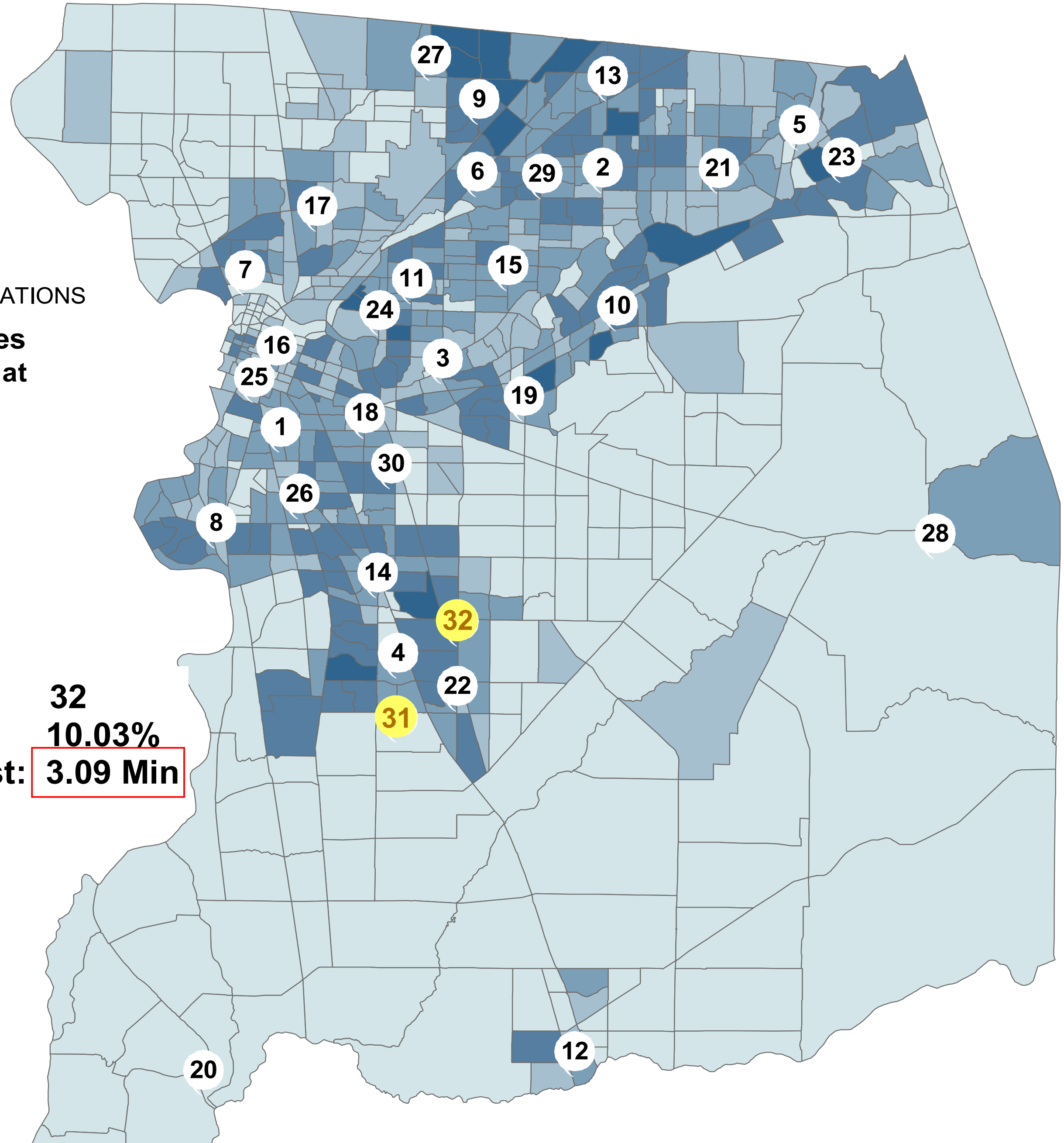
HySS 1 Model

Legend

(HYPOTHETICAL STATIONS

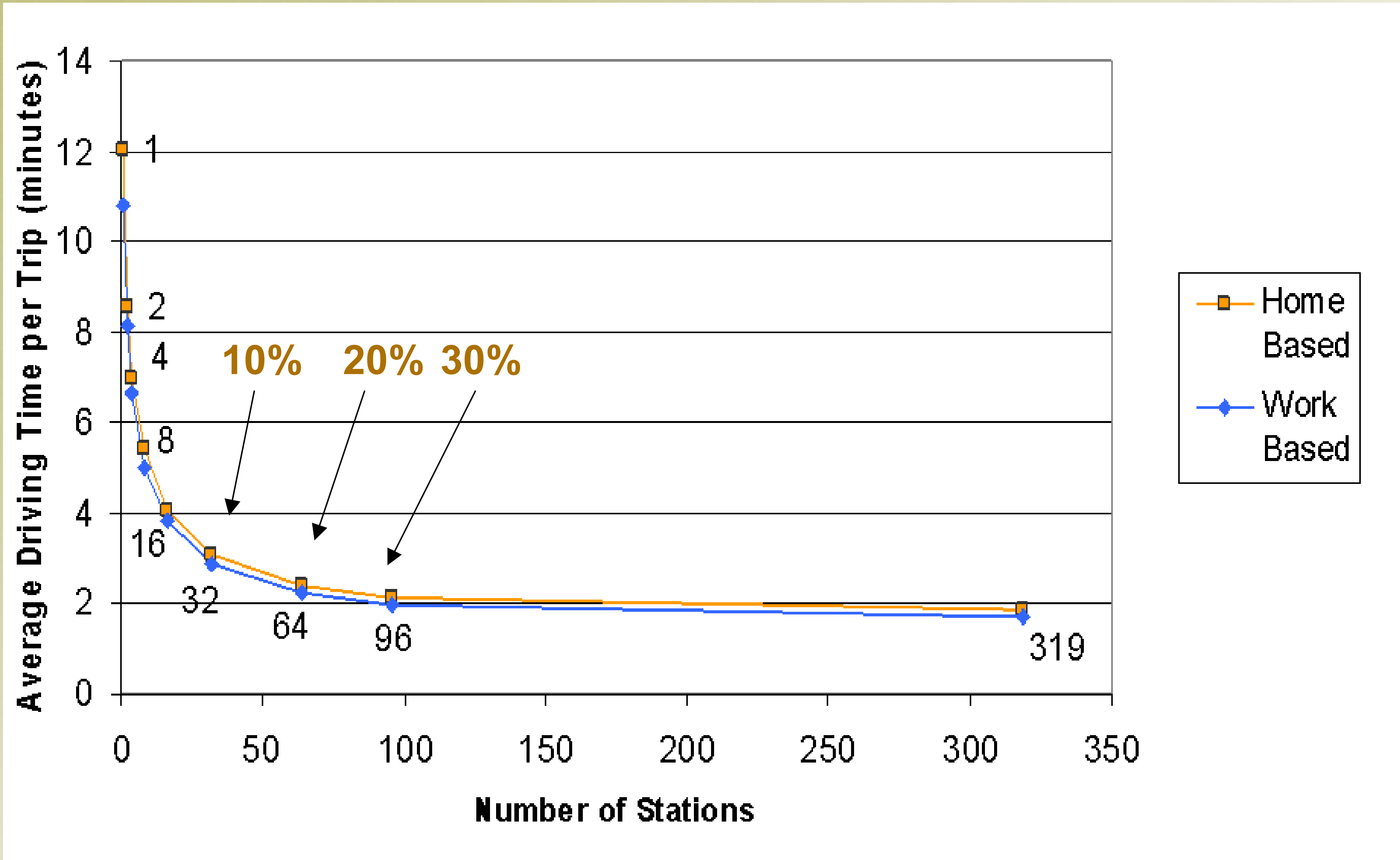
Traffic Analysis Zones
Vehicles leaving zone at 6:30 - 7:30

- 0 - 211
- 212 - 491
- 492 - 798
- 799 - 1259
- 1260 - 2125

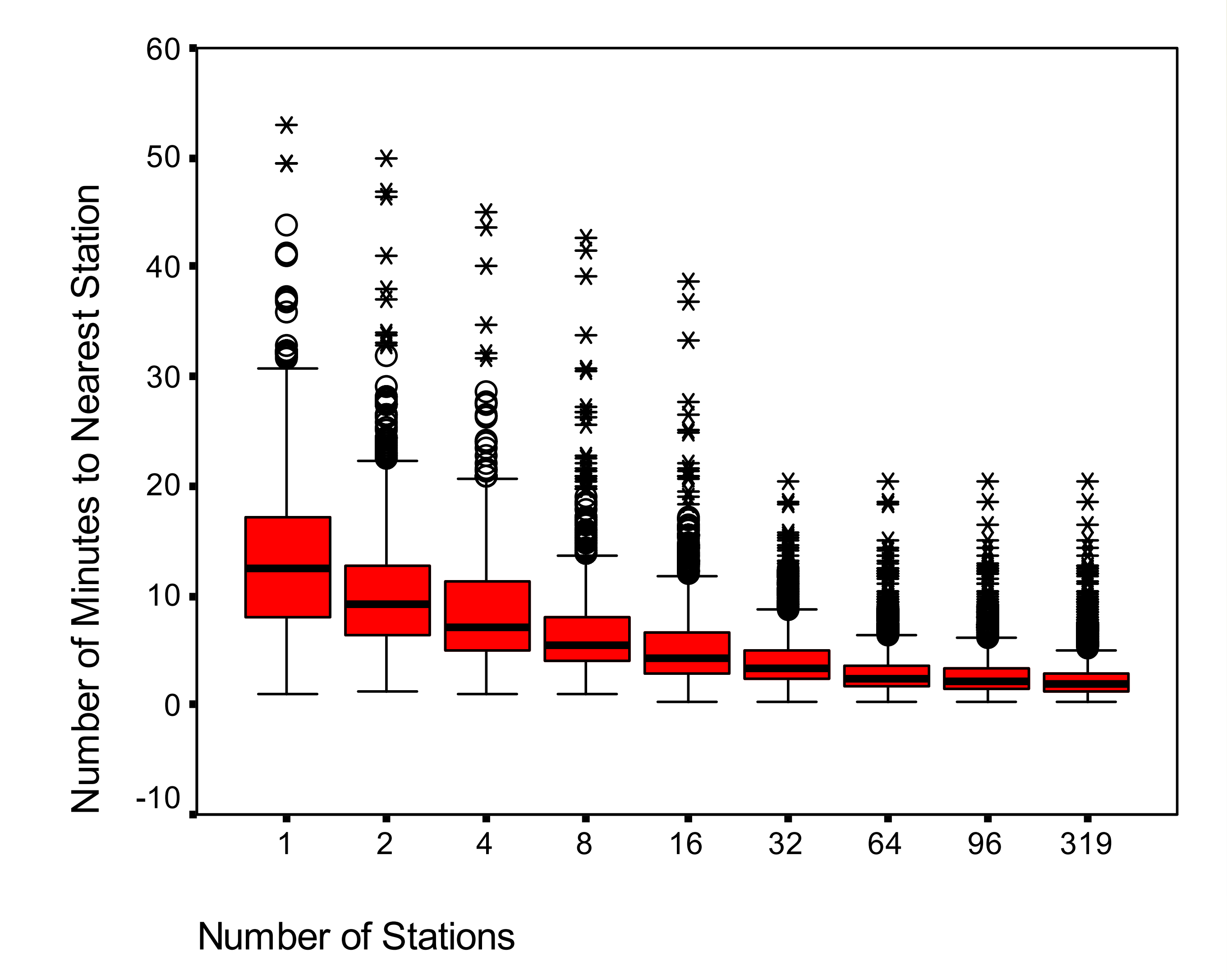


Number of Stations: 32
Percent of Stations: 10.03%
Avg. Time to Nearest: 3.09 Min

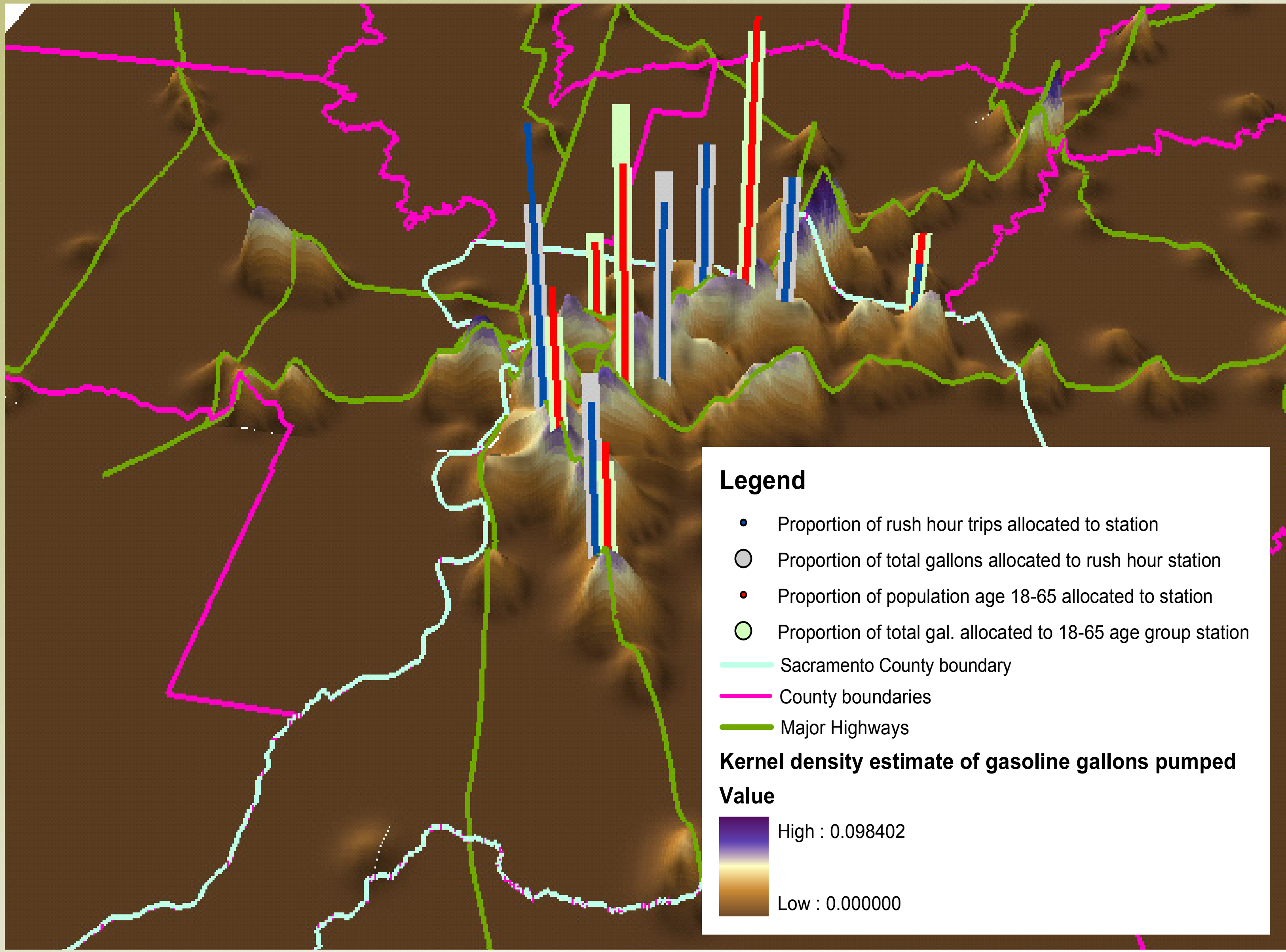
Relationship Between Number of Stations and Average Travel Time



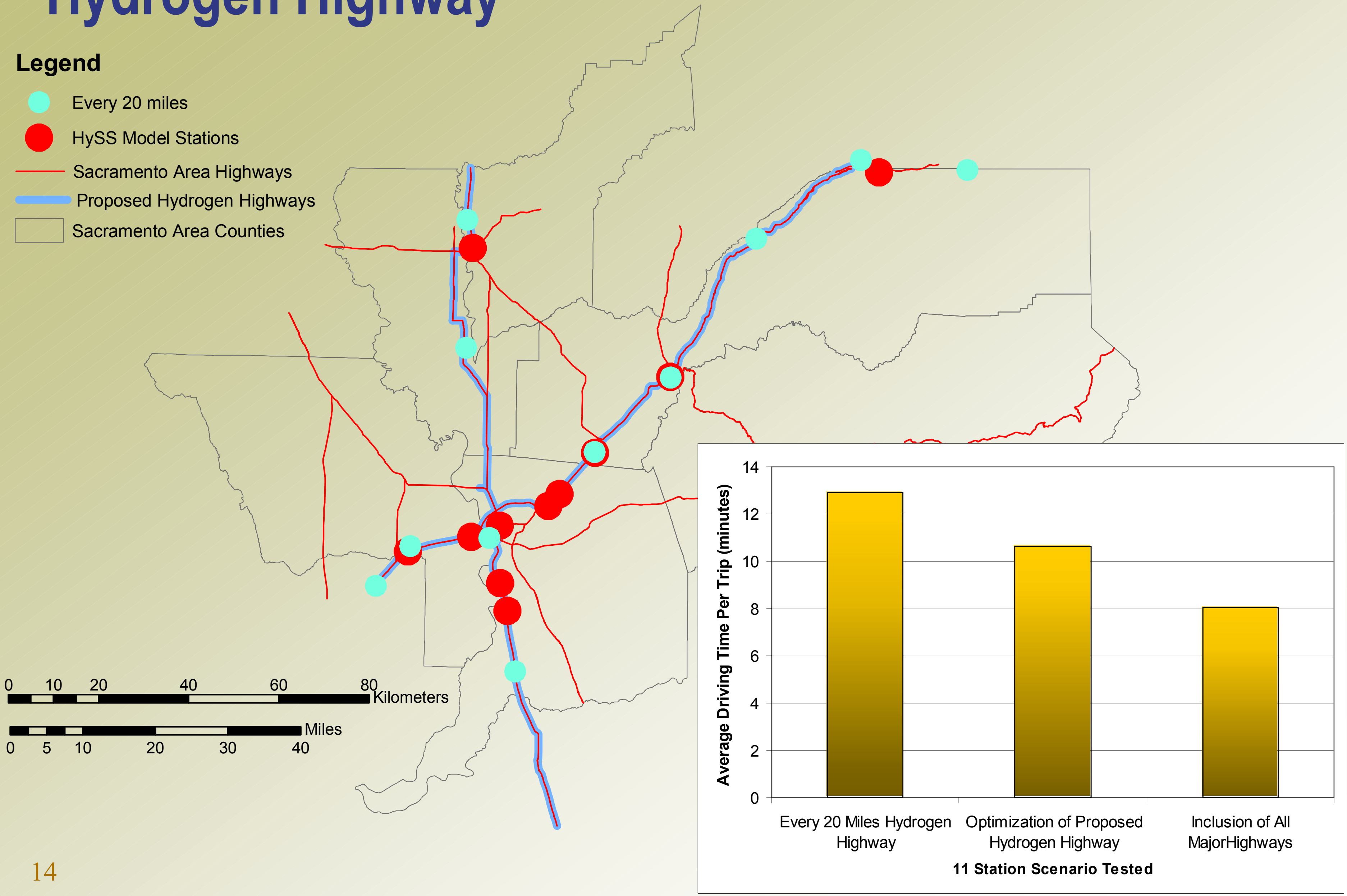
Boxplot (Median, Quartile, and Extreme Values for time from station to zone)



Comparing the Model to the Existing Network

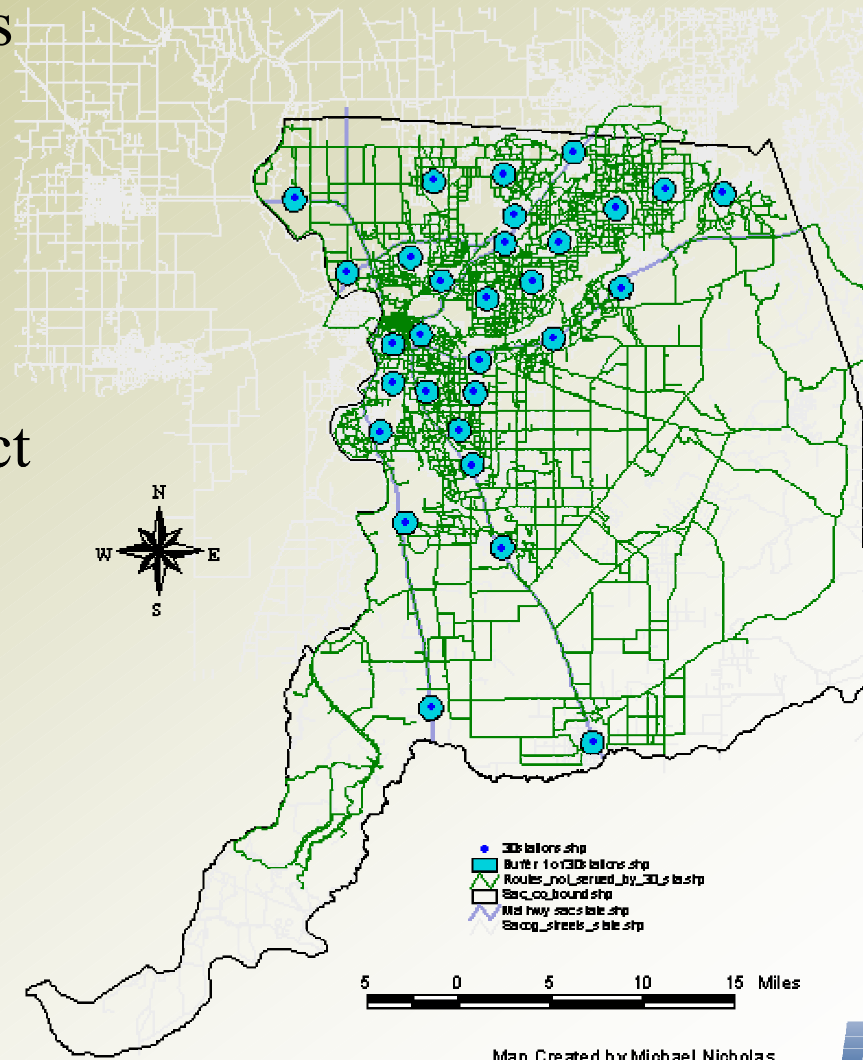


Hydrogen Highway

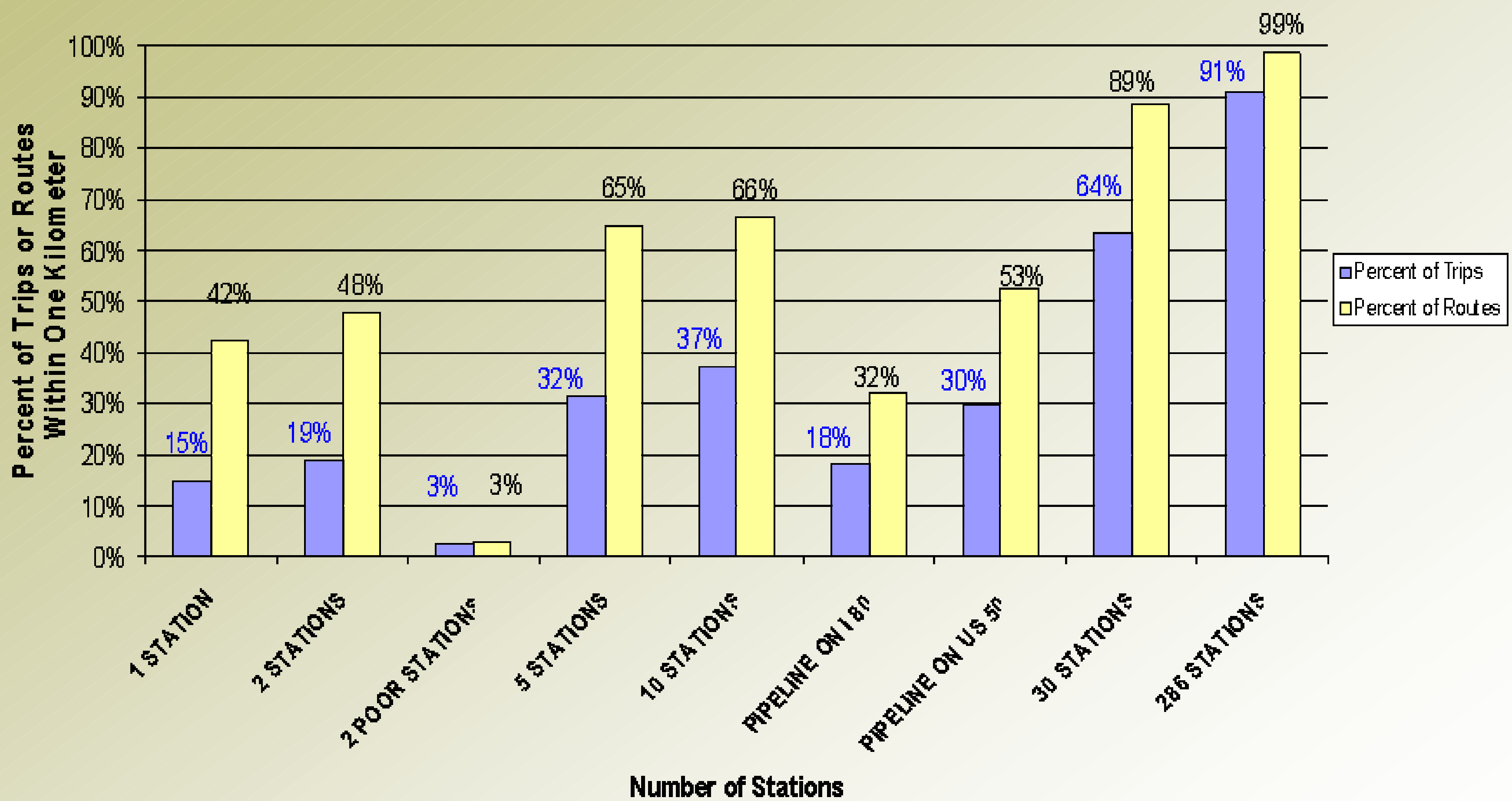


Pass By Model – Another Approach

- Generate paths for OD pairs with Network Analyst
- Create 1km buffers around stations
- Calculate the percentage of routes and trips that intersect the buffers

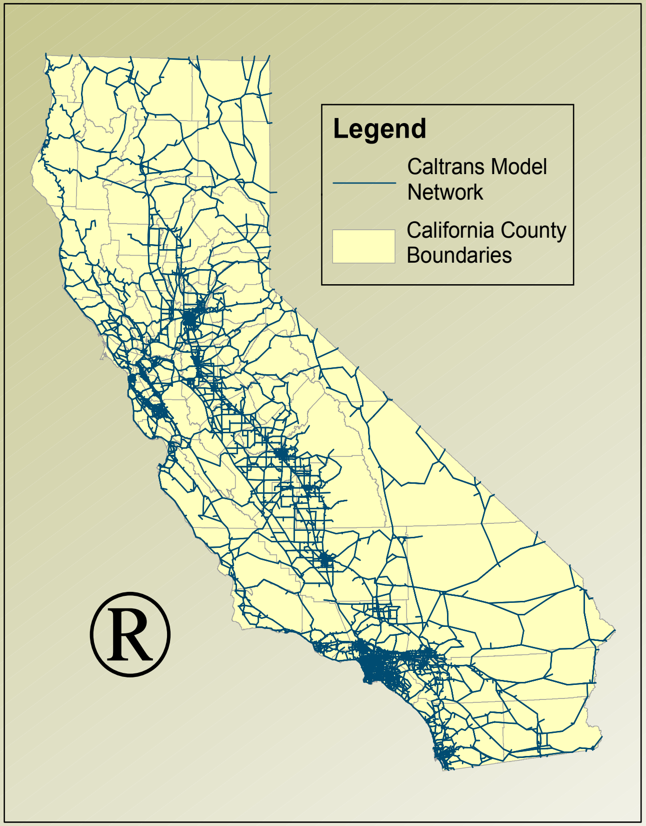


Pass by model – Initial Findings

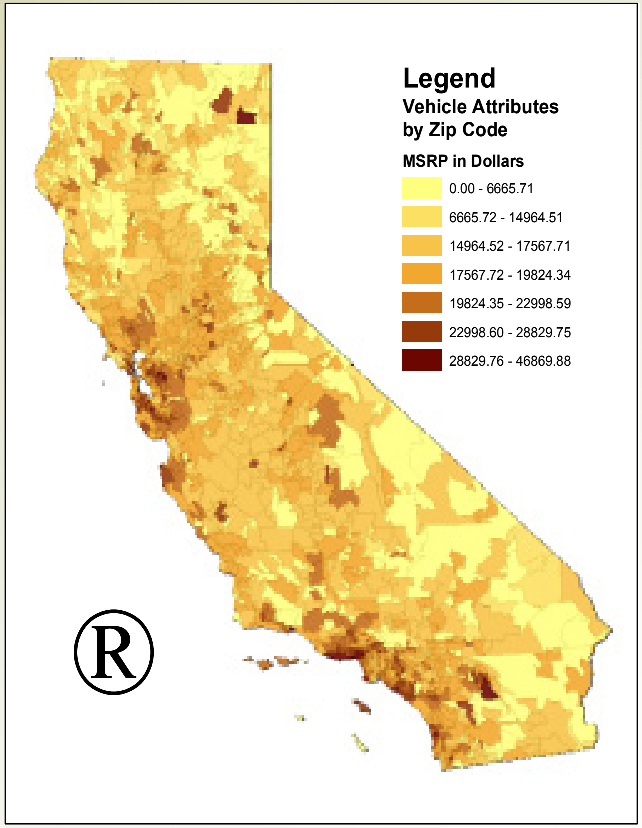


Estimating Interregional Demand

Caltrans Statewide Traffic Model



Average MSRP of vehicle fleet by Zip code (DMV & CARBITS)



Future Directions

- Identify markets within a TAZ and re-run traffic model to derive traffic flows for hydrogen vehicles only
- Incorporate refueling survey data into the evaluation method
- Calculate the time to deviate to a station on the way from work
- Integrate methods from the field of operations research to refine method and incorporate supply considerations
- Expand the model to examine inter-regional refueling networks

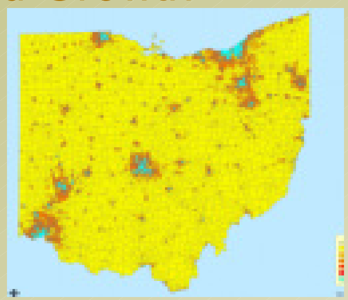
Regional GIS Case Studies of Supply and Demand

- H2 demand is geographically specific. This impacts distribution modes, and primary energy supplies used.
- Finding lowest cost H_2 supply for particular demand and location, involves a trade-off between production and distribution costs.

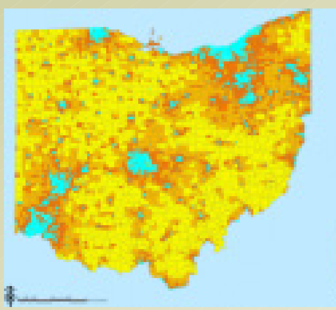
<u>Example: H2 from Coal in Ohio</u>

H2 Demand Growth

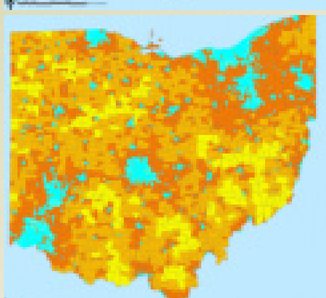
Yr 1



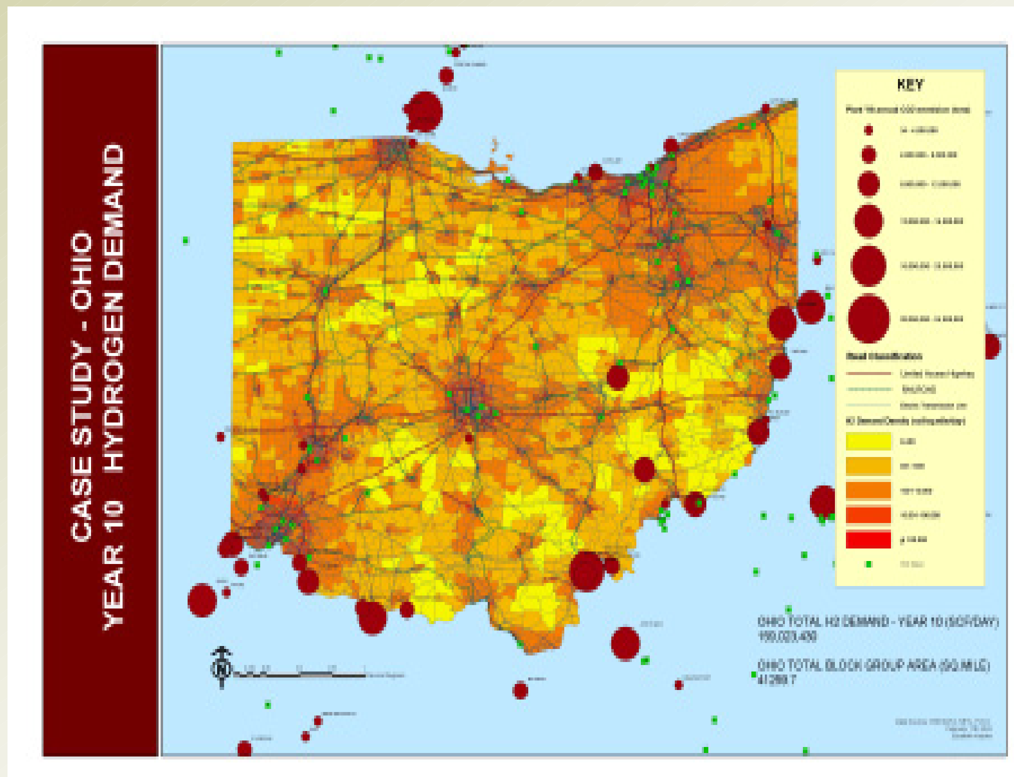
Yr 5



Yr 10

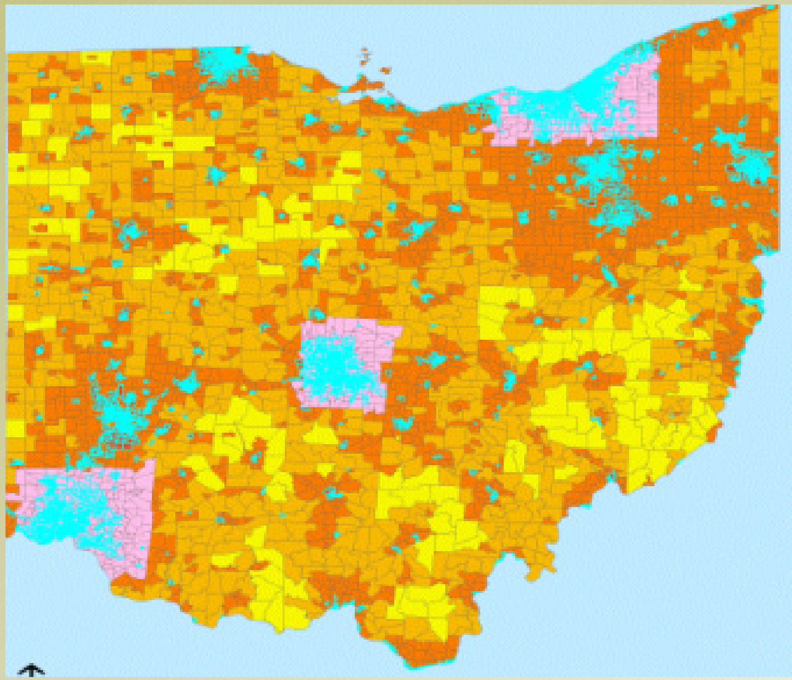


H2 Demand, Existing Energy Infrastructure



Using GIS Tools to Match H_2 Demand & Supply

Highlight urban areas to find total H_2 demand in a city



For example, if 18% of cars use H2:

Cleveland: 60-120 tonne/d

Columbus: 44-88 tonne/d

Cincinnati: 46-92 tonne/d

<u>State</u>: 384-768 tonne/d

<u>Large Coal H2 Plant</u> ~ 600 tonne/d

<u>OBSERVATIONS</u>: The 3 largest urban areas account for ~40% of state H_2 demand, but many people live in areas with lower demand density, where infrastructure might be more expensive

Each city has H_2 demand, ~10-20% the size of a large coal -> H_2 plant. One large coal->H_2 plant could serve entire state, but long distance distribution would be needed (by pipe or truck). => **local, smaller scale H_2 production might be preferred for this level of H_2 demand.**

A Simple Integrated H2 System Model Using Input from GIS Database

Estimate infrastructure design and costs as fcn. of small number of <u>key variables</u> embodying averaged and/or simplified information about:

- H2 markets (fraction of H2 vehicles in fleet, size, station size and coverage)
- Geographic factors (city size, geog. density of demand, location of supply w.r.t. demand) derived from GIS database
- Cost and performance of H2 technologies (vehicles and infrastructure)

- **GOAL: Develop insights and rules of thumb for low cost H2 transitions under different geographic and market assumptions.**

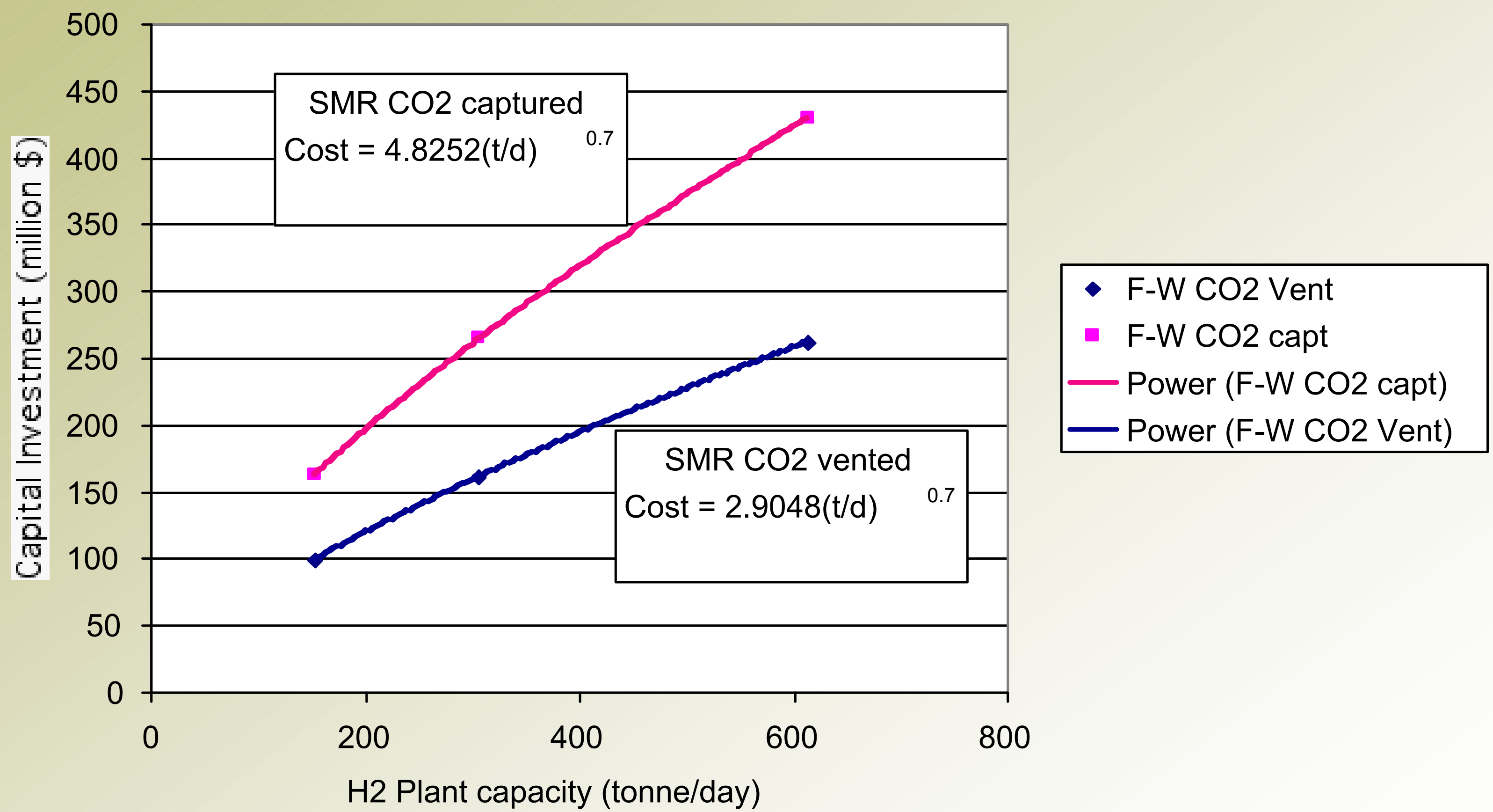
A Simple Integrated H2 System Model:

Engineering/economic models for H2 Technologies:

Cost and Performance vs. scale:

- **CENTRALIZED, LARGE-SCALE PRODUCTION OF H2 FROM:**
  - ***Steam reforming of natural gas w/ and w/o CO_2 sequestration***
  - ***Coal gasification w/ and w/o CO_2 sequestration***
  - ***Biomass gasification***
  - ***Large scale electrolysis***
- **DISTRIBUTED PRODUCTION OF H2 AT REFUELING STA. FROM:**
  - ***Natural gas reforming***
  - ***Electrolysis using off-peak power***
- **FOR CENTRALIZED PRODUCTION, MODEL H2 DELIVERY VIA TRUCK (COMPRESSED GAS OR LIQUID), OR GAS PIPELINE.**

Capital Cost of H2 Plants Using Steam Methane Reforming with and without CO2 sequestration versus plant capacity



Geographic, Market and Technical Inputs for Simplified, generic design of H2 infrastructure

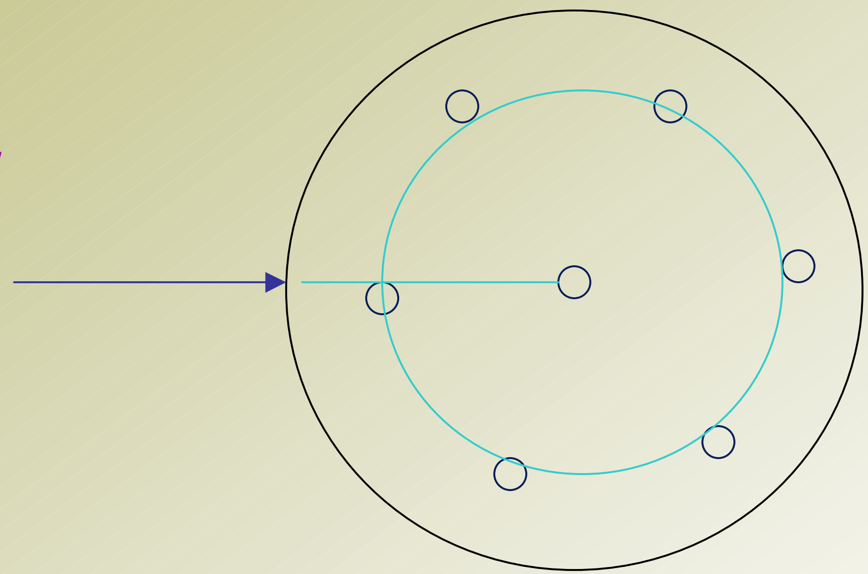
H2 Plant (production method, size, location, shared or dedicated, storage)=>

Production cost + Delivery system requirements

(H2 plant -> city gate + local distrib to H2 sta)

trucks, route length; pipeline length

Population, city size (km^2), # veh/person



Fraction H2 veh. (market penetration rate); vehicle fuel econ + usage =>

city H2 demand

Idealized model of city =>

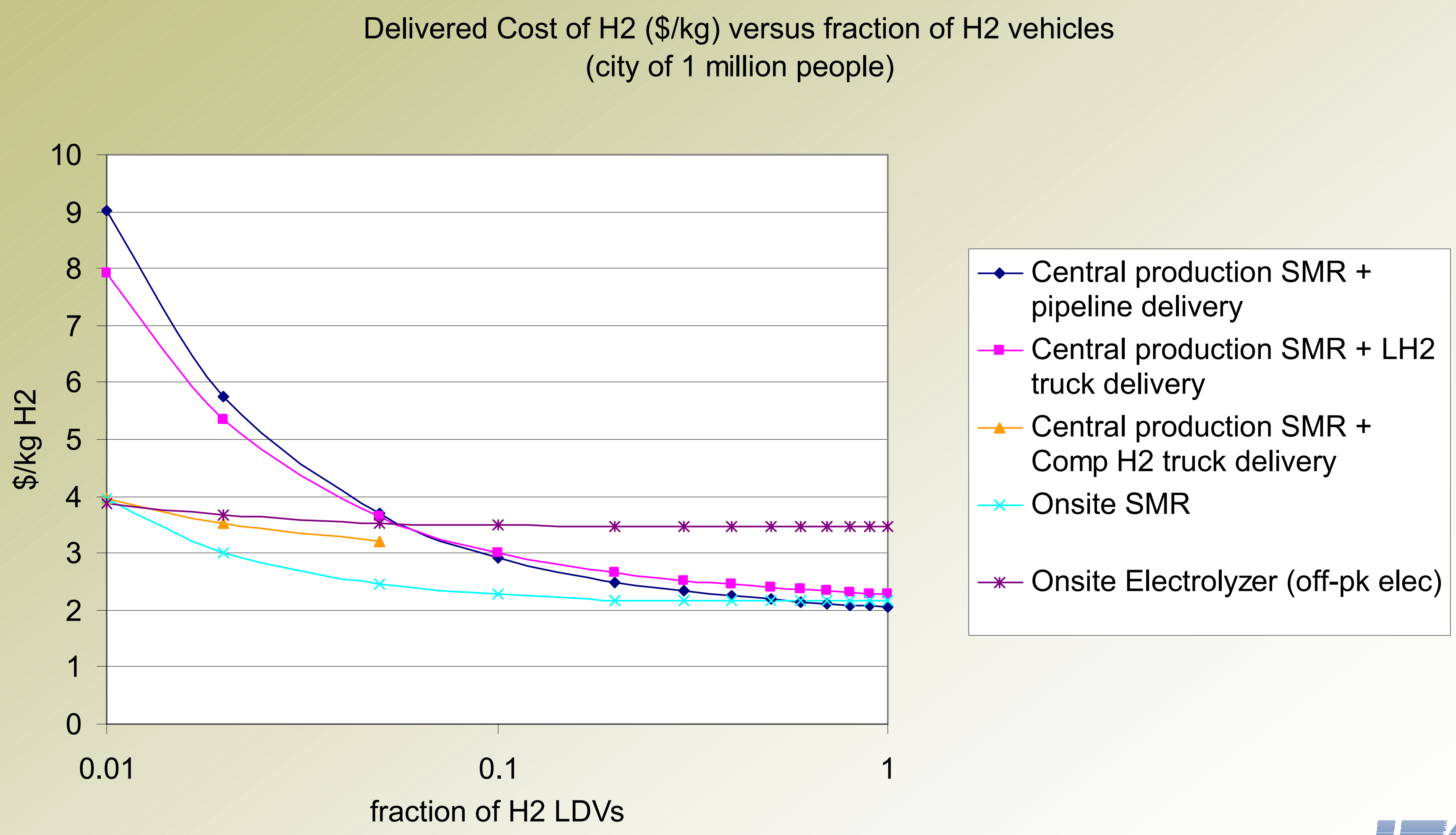
siting of stations

Min. # H2 refuel sta. (coverage=10-25%)

Min & max size for stations (markets, tech) =>

Size and # of H2 sta.

Steady State Results: Deliv. H2 cost ($/kg)



Steady State Results:

- The lowest cost H2 supply option depends on the level of demand, and size of the city, and the density of demand.
- Pipelines are lowest cost delivery option for large, dense cities with high fractions of hydrogen vehicles.

Next Steps

- Include time dependence
- Find lowest cost transition paths over time using dynamic programming methods
- Perform sensitivity studies

H2 System GIS Modeling:
Results (2003-2004) and Future Work

- GIS analysis of hydrogen station siting
  - Adequate convenience with about 10-30% current gasoline sites
  - A model has been developed that estimates station siting based on data about traffic flow, population and city structure
  - Future: Add infrastructure to analysis
- Developed simplified EXCEL model of entire H2 system including production, storage, distribution and refueling.
  - Developed method to find H2 costs v. market penetration, city sizes and population densities, technology assumptions.
  - Idealized models of cities and hydrogen distribution system
  - Future: Improve performance and cost estimates of H2 components; Sensitivity studies
- Development of Transition Model is Underway
  - Now developing methods to include time dependence to model transitions

Appendix:
Hydrogen Pathways Program Information

Overall H2 Pathways Program Goals

- **Research** Conduct cross-cutting research that provides foundation to address key issues and strategies involved in a transition to a hydrogen economy.
- **Public Process** Engage sponsors and interested parties in developing vehicle and fuel-infrastructure roadmaps for the US – and aggressively disseminate research findings. Build upon and partner with CaFCP, DOE, and other outreach initiatives.
- **Graduate Education** - Develop competent engineers, business leaders and policy makers with an in depth and interdisciplinary knowledge of hydrogen as a transportation fuel.

H2 Pathways: Current Research Projects

1. EARLY MARKETS: STRATEGIES AND PATHWAYS
   - CNG/H2 Heavy Duty Bus and Infrastructure Evaluation
   - Opportunities for Using Existing Hydrogen Infrastructure
   - Understanding Innovation Processes and Lessons Learned
2. LIGHT DUTY VEHICLE AND FUELS MARKET RESEARCH
3. DESIGN AND ANALYSIS OF HYDROGEN FUEL STATION AND DISTRIBUTION INFRASTRUCTURE
   - Hydrogen Energy Station Analysis
   - Analysis of Economics and Scale Economies for Refueling Options
   - Compendium of H2 Refueling Station Costs
   - Hydrogen Production Cost and Technology Review and Summary
   - GIS Analysis of H2 Infrastructure Deployment Strategies
   - Development of New Methods for Modeling Regional H2 Infrastructure Development
   - Assessing the Reliability of a Hydrogen Based Energy System
4. H2 PATHWAY POLICY ANALYSIS
   - Policy Analysis for Hydrogen Infrastructure
   - Analysis of Hydrogen Infrastructure Investments and Risks
   - Evaluation of Scenarios for Hydrogen Vehicle and Fuel Introduction
   - Hydrogen Action Agenda for California
5. LIFECYCLE COST AND EMISSIONS ANALYSIS
   - Comparison of Fuel Cell Vehicles and Hybrid Electric Vehicles
   - Manufacturing and Lifetime Cost Analyses for FCVs

H2 Pathways Research Personnel

H2 Research Track Directors

Dr. C.J. Brodrick, Manager, Heavy Duty Fuel Cell Vehicle Program
Dr. Andy Burke, Director, EV Power Systems
Dr. Mark Delucchi, Research Scientist
Mr. Anthony Eggert, Associate Research Director
Dr. Paul Erickson, Assistant Professor (Mechanical Engineering)
Dr. Ken Kurani, Research Engineer
Mr. Jonathan Hughes, Program Manager
Dr. Marshall Miller, Manager, Hydrogen Bus Program
Dr. Tim Lipman (UC Berkeley)
Dr. Joan Ogden, Associate Professor & Energy Policy Analyst
Dr. Daniel Sperling, Director of ITS-Davis
Dr. Tom Turrentine, Research Anthropologist
Dr. Chris Yang, Systems Analysis Research

Key Researchers

Ethan Abeles, MS Student
Nico Bouwkamp, Graduate Student
Andrew Burnham, MS Student
Matthew Caldwell, PhD Student
Gustavo Collantes, PhD Student
Monterey Gardiner, PhD Student

Reid Heffner, PhD Student
Ryan McCarthy, PhD Student
Zhenhong Lin, PhD Student
Jason Ni, PhD Student
Michael A. Nicholas, MS Student

Kenth B. Pedersen, PhD Student
Jonathan Weinert, PhD Student
Brett Williams, PhD Student
Emily Winston, PhD Student

Current Program Sponsors

TOTAL

ConocoPhillips

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